Some Effects of Burning on Forest Soils of Western Oregon and Washington

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THE OBJECTIVE of modern industrial forestry for maximum sustained yield production from timberlands, is dependent upon (1) prompt and adequate restocking following clearcutting, and (2) maintaining the highest possible growth rate in new timber stands. Ability to cut to maximum sustained yield capacity requires prompt restocking of cut-over lands, since the rate of cutting is determined today by future rate of volume replacement by young stands. Properties of forest soils in which trees are grown affect significantly the degree to which these objectives can be realized. It is important that the properties of forest soils, as they affect establishment and growth of new stands, are known, as well as changes in these properties brought about by various kinds of land management operations. Fire is one of the most significant of these factors.

Crown Zellerbach's program of forest soils research began in the summer of 1948. One of the first major studies undertaken was the effects of fire on particular soil types found on the company's timberlands, and interpretation of the soil changes caused by fire in terms of establishment and growth of reproduction stands. This represents only one aspect of the many unanswered questions on Pacific Northwest forest soils. Some of the conclusions are necessarily tentative. This paper is a progress report using the case-history method of presentation.

Studies Initiated

Two studies were made of the effect of burning on forest soil. (1) Examination in the field and laboratory of soil samples from selected burned and unburned control plots immediately after the burns, and periodically thereafter. (2) Study of the soils of specific problem areas where poor reproduction, growth, health, or survival have been outstanding enough to justify special attention. Slash burning or the fire history on some of these areas appears to be the principal factor causing degraded condition or performance.

Selected Burn Areas Project

Plot Location and Description

Clatsop plots—An accidental fire in logging slash on the westward slope of the coast range in Clatsop County, Ore., provided the first test plot location. Plot A was selected to represent "hard burned" conditions, where all organic surface matter was consumed and the exposed mineral soil was colored brick red. Plot B was selected to represent "moderately burned" conditions, where the forest litter and a large portion of the humus was consumed, but where the exposed mineral soil was not reddened. An unburned area nearby provided a control plot for both burned plots. The soil is a mellow, almost a silt loam and has an effective rooting depth around 44 inches. The underlying bedrock is fractured basalt. Many large bedrock boulders are scattered about on the surface. Elevation is 1,760 feet; annual rainfall 90-100 inches. The original forest was the Sitka spruce-western hemlock mixture common in the wet belt along the coast.

Clackamas plots—These are all located on the west slope of the Cascades in Clackamas County, Ore. Plot A was established at a landing cleanup burn where "hard burned" conditions prevailed and mineral soil had been red-burned in patches over much of the surface. An adjacent unburned control plot was also established. Average annual rainfall is about 50 inches; elevation is 2,300 feet. The loam to clay loam soil is 40 to 48 inches deep over hard igneous (andesitic) bedrock. It is somewhat gravelly. About 25 percent of the soil volume is taken up by large fragments of bedrock.

Plot B was set up in a controlled slashing cleanup fire. "Moderate burned" conditions prevailed where little of the surface soil had been reddened but nearly all the litter and much of the humus had been consumed. An unburned control plot was also laid out as near as possible to the burned plot. The soil is a gravelly, almost a clay loam and is 30 to 36 inches deep over hard andesitic bedrock. Twenty to 25 percent of the soil volume is occupied by large bedrock fragments. Elevation is 2,800 feet; annual rainfall averages 50-60 inches.

Plots C and D were located in an extensive logging-slash cleanup burn. The intensity of burning was in the "moderate" range where comparatively little of the mineral soil was discolored red. Most of the litter and humus were removed. A nearby unburned area served as a control plot for both burned plots C and D. The notable difference between these two plots is that plot C has about 25 percent slope while D has about 60 percent. The soil is a loam approaching a clay loam with 44 to 48 inches effective rooting depth. This graduates downward to a layer, one or more feet thick, of partly decomposed bedrock fragments mixed with heavy clay soil lying immediately over the igneous bedrock. Elevation is 1,800 feet; annual rainfall averages about 50 inches. The original forest in the Clackamas area was mostly Douglas-fir with western hemlock and Noble fir increasing with elevation.

Procedure

In each case the procedure was to take representative soil samples from (1) the surface ½ inch after removal of limbs, twigs, and other refuse not an integral part of the soil; (2) the layer down to a 2-inch depth; (3) the zone between 6- and 12-inch depths; and (4) the subsoil at about the depth of maximum root penetration. All plots were sampled initially as soon as possible after the slash burn in late October and early November 1949.

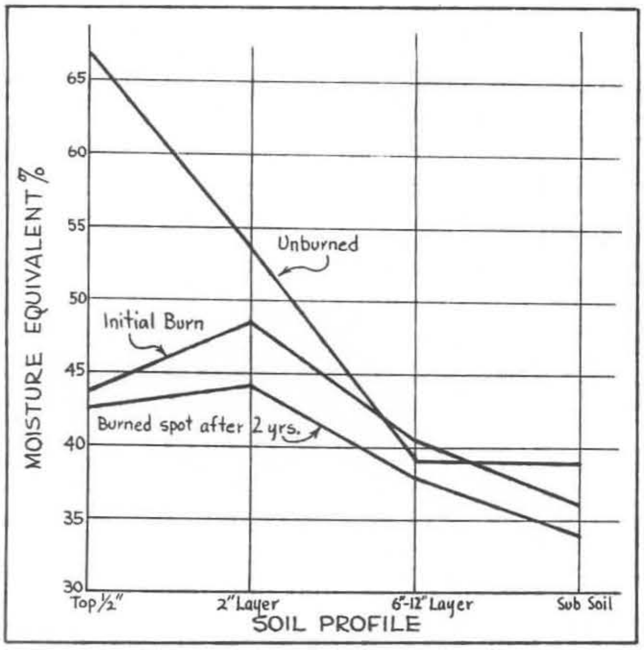

FIG. 1.—Moisture equivalent averages in percent found in studies of burned soils.

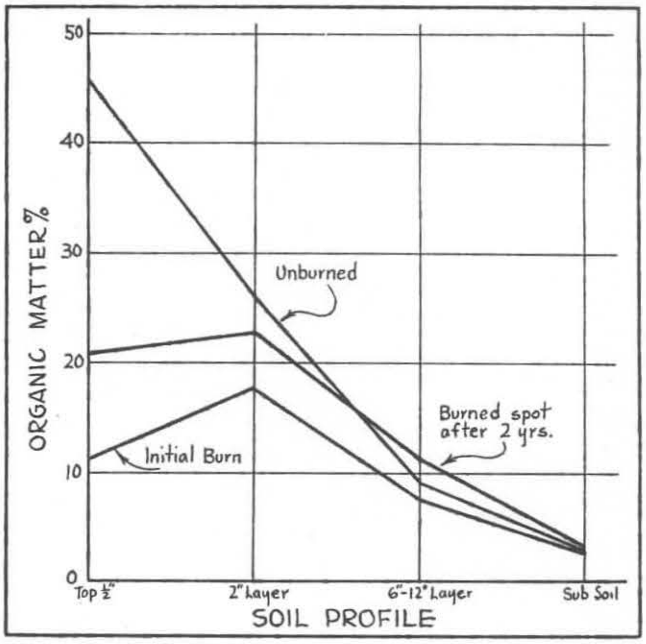

FIG. 2.—Organic matter averages in percent found in studies of burned soils.

The samples of soil taken in September 1951, after the 2-year time lapse, were adjacent to the original spots.

The results of similar tests on all plots have been averaged for clarification. These averages are further simplified by arrangement in chart form so that general trends may be visualized more easily. It must not be assumed that these average test values represent any one specific soil because values from two or more soil types have been assembled. The effects of fire, however, were quite similar on the various soils included in this study. These values are intended to show more simply the general effects and the amount of disturbance from the normal that might reasonably be expected whenever forest soil is subjected to moderate or severe burning.

Discussion of Results

Moisture equivalent tests measure the ability of the soil to retain moisture after centrifuging for 30 minutes at 1,000 times the force of gravity. The results of this standard closely approximate the moisture holding performance of soil in the field. Figure 1 shows how burning of logging slash has reduced the average moisture holding ability of the top ½ inch or so of soil by 33.7 percent. This effect has persisted for two years in these study plots. As moisture is a primary need of any growing plant, a reduction of this magnitude can easily be the difference between survival or death of tree seedlings, particularly in border-line cases such as gravelly or shallow soils, or exposed south slopes.

Total organic matter average results (Fig. 2) were obtained by the standard method of oxidation with sulfuric and chromic acids. Burning the slash has reduced this material in the surface ½ inch from 46.3 percent to 11.3 percent—a drop of 75.5 percent based on the original content. The beneficial action of organic matter on soil has been highlighted recently by the advent of chemical soil conditioners such as "Krilium." Some of these beneficial actions are:

1. Improves soil structure by aggregation of soil particles.
2. Improves drainage and aeration.
3. Increases water-holding capacity.
4. Retards moisture loss through evaporation.
5. Inhibits compaction and crusting.
6. Holds erosion to a minimum.
7. Acts as a storehouse for nutrients.

Unquestionably the removal of organic matter is a major loss to the site and this one effect of burning forest refuse probably has more significance than the others combined. Recovery is slow. A lapse of two years after burning shows the burned areas to have 50 percent as much organic matter as the unburned control spots. Results of all other tests made in this study—moisture equivalent, total nitrogen, pH, nutrient elements—are strongly influenced by the presence or absence of organic matter. A deep soil, rich in organic components, can probably withstand a moderate fire and recover well enough to escape serious damage. A shallow or gravelly soil or a steep south slope cannot.

Total nitrogen tests were made by the standard Kjeldahl method. Averages of the results from the six plots are shown in Figure 3. These averages show a reduction of 67 percent in this critical nutrient element (from 0.79 to 0.26). After a lapse of two years the surface soil had returned to 0.48 percent, which is almost double that at the original burn, but only 75 percent of the unburned control average. The extreme low in total nitrogen after burning was found at the hard burned spot on the Clatsop Tree Farm. Here the top ½ inch of soil

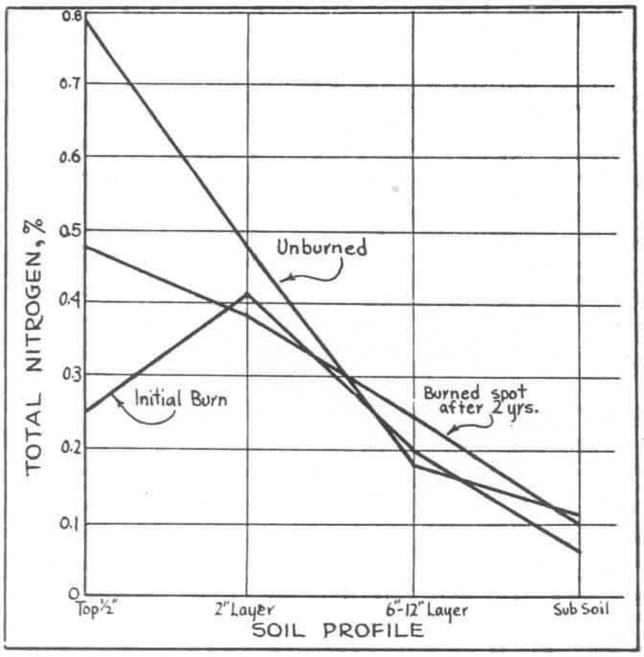

FIG. 3.—Total nitrogen averages in percent found in studies of burned soils.

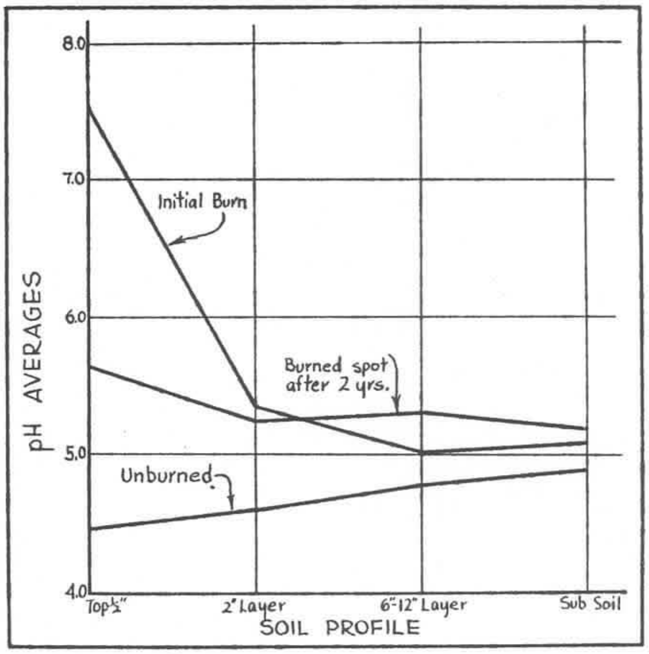

FIG. 4.—Average pH values found in burned soils.

had only 0.04 percent nitrogen immediately after burning. Recovery was about normal, however.

The burning of logging slash releases phosphorus, potassium, calcium, and magnesium—the major nutrient elements—in varying amounts into the soil in soluble or available form. The source of these minerals is the ash from the forest litter of logs, limbs, twigs, leaves, and other organic material consumed in burning. The test method used for these nutrients was devised by Spurway and Lawton at Michigan State College. The amount of available phosphorus was more than twice as high on the burned as on the unburned plots but returned to about normal before the end of two years (Table 1). Potassium was 166 percent higher, but returned to 112 percent by the end of two years. The amount of calcium released was much greater than the other nutrients, reaching 830 percent of the normal unburned soil immediately after the fire. Two years later this element was still 327 percent of that on the control area. The average tests for magnesium show that the amount available in the burned soil was 337 percent of that in the unburned control. By the end of two years this had dropped to normal. The above nutrient test values are the results from the top ½ inch of soil. The effect diminishes considerably by the time the 2-inch depth is reached, but is still noticeable.

This sudden increase of fertility elements in the soil greatly disturbs the balance or ratio between them. This ratio is important, as an unbalanced condition in nutrients can be responsible for poor health and growth of seedlings as stated by Dr. S. A. Wilde.[1] He writes: "In nursery management the state of soil fertility is one of the most important factors that affect the development of seedlings. A deficiency of any of the essential nutrients or an unbalanced ratio has a far-reaching influence on the entire process of metabolism. The ill effects of malnutrition are reflected in abnormal size and color of leaves, inadequate root systems, unbalanced top-root ratio, thin cell walls and porous structure of wood tissue, underdeveloped nuclei in the perenchymatic cells, and other anatomical and physiological abnormalities. Ultimately, all of these ailments result in a decreased resistance of seedlings to drought, frost, and infectious diseases."

[1]Wilde, S. A. Soil-fertility standards for growing northern conifers in finest nurseries. Jour. Agricultural Research 57: (12) 945. 1938.

The pH measurements in this work were made with a glass electrode pH meter. The top ½ inch of the soil became quite alkaline (average pH 7.6) after a slash burn, compared to 4.5 at the unburned control spots. After two years the test had dropped down to 5.7 in the burned spot as against 4.7 unburned (Fig. 4). The highest pH measured after burning was 8.9 in the surface soil of Plot A, Clackamas Tree Farm. Two years later the pH at this spot was 5.9.

Mechanical analysis tests, giving the percentages of sand, silt, and clay in the soil, show that burning of the forest slash and refuse had no significant effect on the quantities of these primary soil particles present.

Results and Conclusions

The measurable physical and chemical effects on the forest soil of burning logging slash are confined to the top two inches of soil depth and usually are concentrated in the ½- to 1-inch depth zone. Two years after burning, the soil in the study plots had only partly readjusted to normal.

In the top ½ inch or so significantly affected by the fire, the average results of all tests made on soil samples taken from the study plots

TABLE 1.—AVAILABLE NUTRIENT ELEMENTS, BURNED SOIL STUDIES. AVERAGE FROM SIX PLOTS[1]

	Initial samples			Two years later
	Burned	*Unburned*	*Burned*	*Unburned*
		Pounds per acre		
		PHOSPHORUS		
Top ½"	37	17	19	10
2" layer	14	19	8	7
6-12" layer	7	4	4	4
Subsoil	4	2	2	2
		POTASSIUM		
Top ½"	184	111	127	113
2" layer	98	54	64	77
6-12" layer	45	30	39	80
Subsoil	27	20	11	51
		CALCIUM		
Top ½"	887	107	350	107
2" layer	160	100	160	93
6-12" layer	67	93	100	93
Subsoil	40	40	70	93
		MAGNESIUM		
Top ½"	81	24	15	13
2" layer	48	6	12	13
6-12" layer	33	19	14	14
Subsoil	20	7	14	13

[1]Values show amounts which would be present in a 6-inch-deep layer of soil, one acre in area, of the same composition as the sample.

TABLE 2.—SOIL AND SITE CHARACTERISTICS—NOBLE FIR PLANTATIONS. CLACKAMAS TREE FARM

	Good growth area	*Poor growth area*
Elevation	2,400 ft.	2,500 ft.
Ave. temp. Apr. to Sept.	50-55 deg. F.	50-55 deg. F.
Ave. rainfall	50 inches	50 inches
Timber type	Douglas-fir-true fir	Douglas-fir-true fir
Position on slope	Middle	Upper
Percent slope	20	25
Aspect	SW	SW
Soil	Clay loam	Clay loam
Texture	Medium	Medium
Stoniness, percent	Less than 20	20 to 40
Bedrock	Igneous, Andesitic	Igneous, Andesitic
Effective rooting depth, inches	40	28
Logged	1942	1943
Burned	1943	1944
Planted	1946	1948
Moisture equivalent	32.8	30.9
Organic matter, percent	13.5	13.0
pH	5.3	5.3
Nutrient elements, pounds per acre		
Phosphorus	4.0	2.4
Potassium	16	16
Calcium	120	240
Magnesium	8	8
Mechanical analysis, percent		
Sand	27.8[1]	24.8[1]
Silt	37.2[1]	44.2[1]
Clay	35.0[1]	31.0[1]
Gravel[2]	43.5	64.5

[1]Gravel-free soil.
[2]Percent. The material passing the ¼ mesh sieve and retained on the 2 mm sieve.

showed that immediately after a burn:

1. The water holding ability (moisture equivalent) was reduced 33.7 percent.

2. A 75.5 percent loss of organic matter occurred.

3. Sixty-seven percent of the total nitrogen, a critical nutrient element, was lost.

4. The available (easily soluble) quantities of the major nutrient elements phosphorus, potassium, calcium, and magnesium had been increased two to eight fold. The possibility of excessive loss by leaching is indicated.

5. The pH was changed from an acid 4.5, favorable to conifers, to an alkaline 7.6.

Results on samples taken two years after the initial burn showed that:

1. Moisture equivalent had not improved.

2. Organic matter was still below 50 percent of normal.

3. Total nitrogen had recovered to about 75 percent of the unburned control.

4. The quantities of available nutrient elements potassium, phosphorus, and magnesium had dropped back down to about normal. Calcium was still more than three times unburned control value.

5. The pH was reduced to a more favorable 5.7 but is still above the average unburned value.

Germination and early survival of conifers is undoubtedly severely influenced by nutrient imbalances and losses. Moisture relationship disturbances, as indicated by moisture equivalent and organic matter tests, are a much more critical result of the burning of logging slash and forest refuse. This is true particularly in conjunction with extremes of temperature brought about by exposure of the soil surface to elements of weather. It is emphasized when the soil originally has a low moisture supplying ability such as a shallow or gravelly condition, or when steep south slopes are encountered.

Case Histories of Some Problem Areas

Slash or forest refuse burning does, in many instances, degrade forest soil so that regrowth is unsatisfactory as shown by the following examples of problem areas on some of the Crown Zellerbach Corporation tree farms.

Poor Growth of Trees in a Noble Fir Plantation

On the Clackamas Tree Farm, lying on the western slopes of the Cascades in Clackamas County, Ore., there is a plantation of Noble fir where the trees, compared to a nearby planting of the same spe-

cies, are growing poorly. Trees in the poor area, planted in the spring of 1948, apparently were just able to stay alive. Four growing seasons later they had little more foliage than when planted. Those in the better location were from three to six feet high and well developed laterally. Slash fires in both areas previous to planting, had almost completely removed all logging refuse, forest litter, and duff. Only blackened stumps and a few charred logs remained.

Comparisons of results of field and laboratory examinations made on the soil from both areas (Table 2) show that organic matter, moisture equivalent, nutrient elements, and pH tests are nearly identical in the two spots. In contrast, tests of potential drouthiness — effective soil depth, percent of gravel in the topsoil, and position on slope—indicate that moisture available for tree growth is significantly less at the poor growth plantation. Although this area is not expected to produce trees as well as the good plantation, it did produce timber satisfactorily in the past. Some occurrence since the original forest was removed has prevented it from producing again. The only identifiable occurrence of this nature has been slash burning. Undoubtedly fire removed as much humus, limbs, logs, and twigs from the good growth area as the poorer one but because of the deeper, less gravelly soil and better slope location its ability to grow trees has not been measurably degraded. The removal of the same amount of organic forest floor refuse from the less favorable site, however, almost cancelled its ability to produce. The drought hazard of this poorer plantation has been so much increased by loss of moisture holding advantages of an organic blanket, that it has become unable to support proper tree growth. Here is a good illustration of how uncontrolled fire can seriously reduce the productivity of an unfavorable site.

Table 3.—Soil and Site Characteristics—Neah Bay

	Good growth	*Poor growth*
Elevation, feet	600-1000	600-1000
Ave. temp. Apr. to Sept., degrees F	50	50
Ave. rainfall, inches	82	82
Timber type	Spruce-Hemlock	Spruce-Hemlock
Position on slope	Middle	Middle
Slope, percent	20	20
Aspect	West	West
Soil	Loam	Loam
Texture	Medium	Medium
Effective rooting depth, inches	34	34
Substratum	Compact till	Compact till
Logged	1935	1935
Burned	1937	1937
Planted	1944	1944
Moisture equipment	47.4	50.8
Organic matter, percent	16.2	22.1
pH	5.23	4.65
Nutrient elements, pounds per acre		
Phosphorus	4.3	2.8
Potassium	11	0
Calcium	160	0
Magnesium	16	8
Nitrogen (active)	2.7	0
Mechanical analysis, percents		
Sand	43.	43.3
Silt	42.3	40.8
Clay	14.5	15.9

Table 4.—Soil and Site Characteristics, Youngs River Spruce Plantations—Clatsop Tree Farm

	Good growth	*Poor growth*
Elevation, feet	800	800
Ave. temp. Apr. to Sept., F.	57	57
Ave. rainfall, inches	70	70
Timber type	Spruce-hemlock	Spruce-hemlock
Position on slope	Middle	Middle
Slope, percent	10	5
Aspect	Southerly	Northwest
Soil	Silt loam	Silt loam
Texture	Medium	Medium
Substratum	Dense clay	Dense clay
Effective rooting depth, in.	30-36	20-26
Competitive vegetation	Very little	Heavy bracken
General appearance of spruce	Good color and development	Poorly developed, fair color
Logged	1926	1926
Burned	1928	1929 and 1932
Planted	1930	1930 and 1933
Moisture equivalent	47.2	52.8
Organic matter, percent	9.8	15.5
pH	4.6	4.6
Total nitrogen, percent	0.33	0.40
Nutrient elements, pounds acre		
Phosphorus	12	2.4
Potassium	0	0
Calcium	160	0
Magnesium	16	8
Nitrogen (active)	48	0
Mechanical analysis, percent		
Sand	19.5	20.5
Silt	57.8	55.8
Clay	22.7	23.7

Neah Bay Poor Health and Survival Spots

A 1944 plantation of Sitka spruce and Port-Orford-cedar on the Neah Bay Tree Farm, Clallam County, Wash., the northwest tip of the U. S., has developed patches where there is poor survival of planted trees. Poor health of surviving trees and native vegetation is also evident in these spots. To find the cause of these variations a field cruise included intense examination of four of these poor spots, in conjunction with three adjacent good growth areas. Soil samples were taken from both areas and

examined in the laboratory.

Field observations did not reveal any general physical soil conditions responsible for poor growth. Soil depth is adequate, ranging around 30 to 40 inches in both the good and poor spots. Texture is medium and uniform. The substratum is a densely compacted glacial till, characteristic of this soil type. The presence of as many and as large stumps from the original forest in the poor zones as in the good points definitely to some recent activity as being responsible for the degraded condition.

Results of laboratory tests on soil samples taken from both type areas indicate diffrences that are probably responsible for the observed growth and health variations. The level of the alkaline nutrient elements, particularly calcium (Table 3) in the soil from the poor spots shows the low fertility conditions existing here. These same poor spots have a pH from 0.2 to 0.9 lower than the good areas and this again brings out the lack of alkaline elements—calcium, potassium, and magnesium in the soil. Results of the laboratory tests for moisture equivalent, organic matter, mechanical analysis, and total nitrogen do not reveal significant variations (Table 3).

Localized exceedingly hot fires in the original burn or later readily account for the barren patches where there is now poor health and growth. The rapid release, by a hot fire, of all the nutrients stored in the organic matter on the forest floor will leave little for gradual release by decay.

Youngs River Spruce Plantations on the Clatsop Tree Farm

In Clatsop County, Ore., two Sitka spruce plantations are showing extreme contrast in growth and health.

The trees in the good growth area were planted in 1930 after the area had been logged (1926) and burned (1928). The trees are tall, well formed, and have almost completely taken over the site. Those on the poor growth plantation were planted in 1933 after the area had been burned twice (1929 and 1932) following logging in 1926. These trees are stunted and scrubby and dense bracken fern, eight feet and more high, is giving much competition. Elevation in both cases is near 800 feet; rainfall around 90 to 100 inches. Field soil examinations in the plantations did not reveal significant differences, and laboratory examinations yielded the only outstanding variation that was found between the soils of these areas. Available nutrients were on the low side in the poor growth soil (Table 4).

The conclusion was that repeated burning with the accompanying leaching occurring in this high rainfall area depleted the nutrients to such a low level that the conifers were unable to compete successfully for these nutrients with weeds, fern, and brush.

Some of the effects of fire on the physical and chemical properties of these forest soils, and some results of these changes in terms of forest production have been given in this article. Many other effects of fire have not been covered such as erosion, changes in normal floral succession, and effects on the microflora and fauna. Fire can be an enemy or a tool of management. In some cases, it may be a necessary evil. Only by knowing its results can proper evaluation be given to its danger or value in the long-term objectives of forest management.